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THE DUAL ASPECT OF THE 4IR-ENVIRONMENT NEXUS

Working Paper

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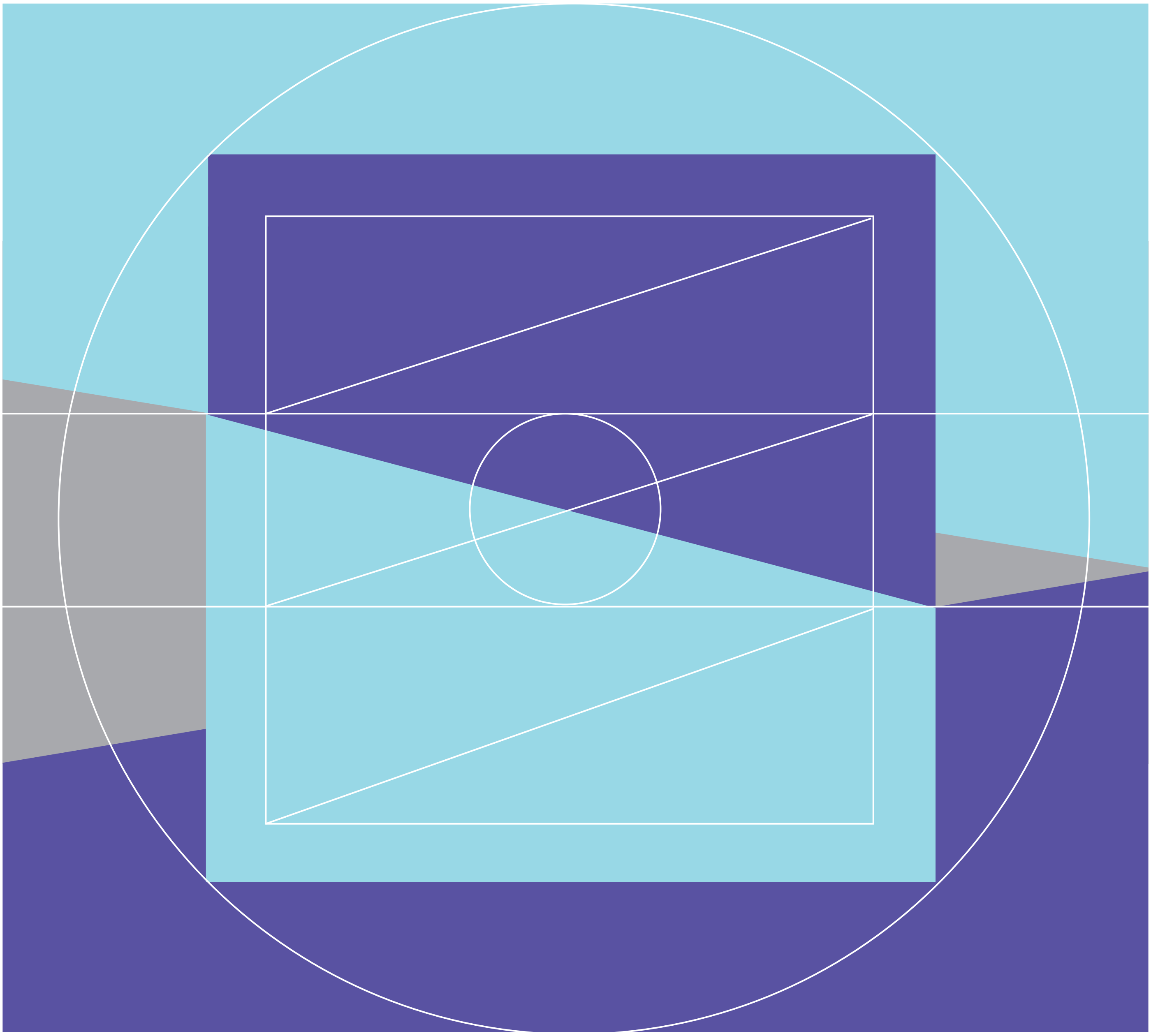

JUNE 2021

The dual aspect of the 4IR-Environment nexus[1]

IN SEARCH OF AN ENVIRONMENTALLY SUSTAINABLE PARADIGM

Contents

[1] Stathis Devves, Yannis Eustathopoulos, Aggelos Sotiropoulos, Force Project, ENA Institute.

Abstract

The relation between environmental and climate policies and the 4th Industrial Revolution is increasingly under discussion. New technologies are both substantial enablers of climate change mitigation/adaptation and sources of rising emissions, electronic waste and environmental degradation.

On the one hand, the 4IR is expected to contribute decisively to cost reduction and efficiency improvements in the energy system, through smart mobility and applications in advanced manufacturing. Besides, artificial intelligence can deliver applications which will improve the capacity of authorities and stakeholders to reduce marine pollutions, tackle desertification and restore degraded land and soil.

On the other hand, new technologies encompass hidden environmental costs due the impact of billions of IoT devices which are expected to prevail in economic and social activities in coming years. Beyond the unsustainable increase of energy consumption, other notable costs include a significant environmental footprint arising from the extraction of critical raw used in digital products and from the rising amount of e-waste.

This policy paper explores the dual aspect of 4IR-related technologies regarding their relation to the environment. First, we proceed with a presentation of the current climate and environmental impact of the digital economy based on available studies. Second, a series of cases studies are presented concerning potential application of new 4IR-related technologies in the industrial, energy and environmental sector which could bring significant benefits for climate mitigation and adaptation. These applications include technologies for (1) the development of Industrial Symbiosis (IS), (2) the design of highly efficient low-carbon and RES-based energy systems, and (3) the creation of various applications improving substantially the capacity to formulate and implement policy actions for the anticipation and adaptation to climate change (e.g. simulation and modelling).

Overall, we conclude that the net climate and environmental footprint of new technologies will be critically dependent on the features of the governance and policy framework of the 4IR which will prevail at international, European and national levels.

1. The climate and environmental footprint of the digital economy

Digital technologies and services have played a key-role for economic and social resilience since the outbreak of the pandemic enabling the transition to telework and the operation of e-commerce, the preservation of social interactions, access to essential public services and the functioning of the education system. As a consequence, this experience is now apprehended as a "window of opportunity" for the restructuring of productive processes both in the private and public sector through a wide implementation of digitization. The consolidation of teleworking, for instance, belongs to the "starters" for business restructuring and expansion in the post-Covid19 era[2]. Unlike telework—whose pros and cons have been actively debated in recent months—the relationship between the digital economy and the environment has received less attention in the public sphere or have been discussed only in one-dimensional way (i.e. focus on positive effects of new technologies for climate and energy transition).

Behind the scenes: the growing environmental impact of the digital economy

Facts

The considerable reduction in greenhouse gas emissions (GHG) observed during the first semester of 2020 in the world has been the result of the slowdown in air and ground transport, combined with the suspension of operations of businesses and industrial units. Impressive satellite images and photos illustrating the reduction of GHG and air pollution flooded the internet. In this context, many media hastened to present the contribution of the digital economy as intrinsically beneficial to climate change mitigation.

This approach is being disputed however by a growing number of studies which explore the broader direct and indirect environmental impacts of the digital economy[3]. Overall, there is growing evidence that the carbon and environmental footprint of the digital sector is increasing at unsustainable rates due to the energy consumption of networks and data

[2] Pinner, D., Rogers, M., Samandari, H. (2020) 'Addressing climate change in a post-pandemic world', McKinsey Quarterly, 7 April 2020. Available at: https://www.mckinsey.com/business-functions/sustainability/our-insights/addressing-climate-change-in-a-post-pandemic-world
[3] Shift Project (2019) "Lean ICT – Pour une sobriété numérique", Résumé aux décideurs du rapport du groupe de travail Lean ICT, Octobre 2018. Available at: https://theshiftproject.org/article/pour-une-sobriete-numerique-rapport-shift

centres and to the environmental impact of mining activities related to digital products. This trend is directly associated with the prevalence of an extremely commercialized market model leading to excessive consumption of digital services, equipment and devices ("digital obesity"):

- **The direct energy footprint** (production and use of equipment) of the digital sector is growing at a rate of 9% per year[4]. At the same time, the energy intensity of the digital sector is growing by 4.0% on an annual basis, in contrast to the energy intensity of global GDP, which declined by 2.1% in 2018[5]. This trend therefore is not compatible with global climate goals.
- **In 2018, the emissions of the digital economy** represented 3.7% of the global greenhouse gas emissions, having increased by 50% since 2013. This percentage is twice the level of emissions of civil aviation (2%)[6]. It is worth noting that the share of the digital economy in global GHG may approach 8% in 2025, corresponding to the current emissions of cars[7]. Indicatively, the forecasted emissions would range between India's and EU' total emissions or 6.3% and 9.1% respectively in 2017 (based on latest available data)[8].
- **Finally, the digital sector is in high demand for valuable and rare raw materials**. Questions are raised about the medium-term sufficiency of these materials and the environmental and social impact of their extraction[9]. Peaks in mineral production is a factor of increasing vulnerability of the digital economy, exposing critical services and infrastructures to cost increases and supply shocks of still undetermined scope. According to forecasts, demand for critical raw material such as lithium could increase

[4] Shift Project (2019), op.cit.
[5] Energy Intensity, Global Energy Statistical Yearbook 2020.
[6] Shift Project (2019), op.cit.
[7] Shift Project (2019), "Climate crisis: The unsustainable use of online video" (executive summary). Available at: https://theshiftproject.org/wp-content/uploads/2019/07/Excutive-Summary_EN_The-unsustainable-use-of-online-video.pdf
[8] Global Emissions, Center for Climate and Energy Solutions, https://www.c2es.org/content/international-emissions/
[9] De Ravignan (2020), "Les métaux rares mettent le monde sous tension", Alternatives Economiques No 397, 22.1.2020. Available at: https://www.alternatives-economiques.fr/metaux-rares-mettent-monde-tension/00091351

by 18 times in 2030 and 60 times in 2050[10]. As a result, decisions in favour of the exploitation of Europe's mineral resources could be adopted—despite obvious environmental and social costs—with a view to reduce the dependency on third countries regarding imports of critical raw materials[11]. Such a development would confront European local societies with the contradictions characterizing the environmental and the digital transitions.

Causes

As mentioned, these trends are related to the over-consumption of digital equipment and services, which is overwhelmingly found in developed economies. On average, a US resident owns 10 connected devices (smartphones, tablets, computers, smart TVs, game consoles, etc.) corresponding to an average consumption of 140 gigabytes, compared to a single device in India and a consumption of 2 gigabytes[12]. The massive entry of China and India's populations into the digital era—combined with the development of the 5G network with its increased energy consumption compared to 4G[13]—is therefore expected to increase substantially the global environmental footprint of the digital sector.

Overall, maximizing the contribution of the digital sector to sustainable development seems to be at odds with current market conditions both in terms of demand and supply of services. This makes it necessary to draw up new strategic priorities in order to optimize the socio-economic impact of digital infrastructures and services while reducing in parallel the environmental footprint of the sector. Improving the circularity of the economy is an important first step in this direction, with the aim of designing environmentally responsible

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[10] Cited in European Commission, '2020 Strategic Foresight Report: Charting the course towards a more resilient Europe'. Available at: https://ec.europa.eu/info/sites/info/files/strategic_foresight_report_2020_1.pdf'

[11] According to the 2020 Strategic Foresight Report of the European Commisison "*Europe's own mineral resources are under-exploited, and the EU has vulnerabilities in processing, recycling, refining and separation. This is due to high production costs compared to global market prices, high environmental standards and current low levels of public acceptance. Investment in the production of primary and secondary raw materials would benefit employment in all manufacturing industries (…) These investments could help retain existing geological and metallurgical high-tech skills and develop new ones to boost the EU's global competitiveness in a sector that has solid growth potential in the 21st century*".

[12] Shift Project (2019), op.cit.

[13] "5G base stations use a lot more energy than 4G base stations: MTN", Fierce Wireless, 3.4.2020. "Will 5G and edge increase network energy consumption or improve efficiency?", DCD, 12.2.2020. "MWC19: Vertiv and 451 Research Survey Reveals More Than 90 Percent of Operators Fear Increasing Energy Costs for 5G and Edge", Vertiv, 27.2.2019.

products and services: repairable and recyclable products with a significantly increased product life cycle. Despite increasing amounts of electronic waste, recycling of material and devices remains very weak globally[14].

The European Green Deal initiative to establish a "Right to repair" is therefore key in order to enable the greening of the ICT industry. An effective and broad implementation of the 'Right to Repair'[15] could support the development of local labour-intensive enterprises in the circular economy for electronic devices (repair, recycling) with a special attention to the support of social and cooperative enterprises. Most member-countries, and especially those with high-levels of youth unemployment, would benefit from the development of such sustainable businesses.

Despite the growing environmental impact of the digital sector, the 4IR certainly encompasses significant enabling technologies for mitigating climate change, promoting climate adaptation and contributing to the preservation of the environment. However, these possibilities, although widely mentioned in the public discussion, should not be taken for granted, as bottlenecks of technological, legal and socio-economic nature hinder their development and optimal use as pointed out in the following section.

[14] Delépine, J. (2020) 'L'insoutenable croissance du numérique', Alternatives Economiques n°397, 15/01/2020.
[15] Parliament wants to grant EU consumers a "right to repair"

2. Cases studies

In this section, three (3) case studies concerning applications of 4IR-related technologies in the industrial, energy and environmental sector are presented. As examined, these applications encompass a strong potential for climate mitigation, climate adaptation and environmental protection and include technologies for a) the development of Industrial Symbiosis, b) the design of highly efficient low-carbon energy systems and c) the use of simulation and modelling for the anticipation of the consequences of climate change.

2.1 Case study 1: Industrial Symbiosis & Industry 4.0

2.1.1 Industrial symbiosis & SDGs

Industrial symbiosis (IS) is the concept in which two (2) or more industries are exchanging, or sharing resources in a system under which the waste or byproducts of one (1) industry become raw materials of another[16] thus forming an industrial interconnected ecosystem which benefits from the exchange of resources flows among the different related entities. The resources used may broadly be defined as waste, by-products, residues, energy, water but also logistics, capacity, expertise, equipment and materials. The symbiotic concept thus results to the maintaining of these resources in production for longer periods of time[17].

[16] EREK (2019) Quarterly - July 2019. Industrial Symbiosis. Publications Office of the European Union. Available online: https://www.resourceefficient.eu/sites/easme/files/EREK%20Quarterly%20Issue%20%2304.pdf

[17] European Committee for Standardisation-ECS. (2018). CEN Workshop Agreement 17354. Available online: https://standards.iteh.ai/catalog/standards/cen/e193aac6-2c81-442d-9309-ecdcdd62b24f/cwa-17354-2018

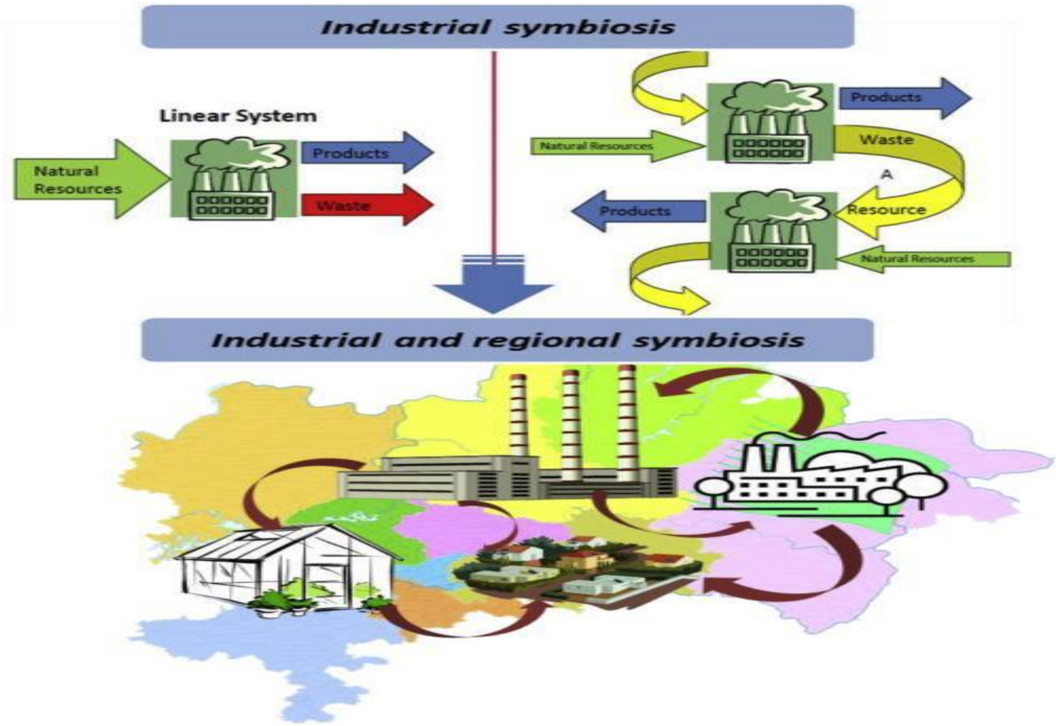

Figure 1. Industrial symbiosis concept (including regional symbiosis)[18]

If implemented in a sustainable way, the use of the IS model may produce substantial socioeconomic and environmental benefits. These may include among others:

<u>Environmental benefits (Contributing to the achievement of SDGs 8, 9, 11, 12, 13 and 17)[19]</u>

1. Reduction of overall Greenhouse Gas (GHG) emissions of the industrial sector through the reuse, recovery and recycling of waste
2. Protection of the environment through a more efficient use of resources such as water and energy

[18] Hong Li, Liang Dong, Jingzheng Ren. 2015. Industrial symbiosis as a countermeasure for resource dependent city: a case study of Guiyang, China. Journal of Cleaner Production. Volume 107. Pages 252-266. ISSN 0959-6526. https://doi.org/10.1016/j.jclepro.2015.04.089.
[19] International synergies. 2021. Available online: https://www.international-synergiesni.com/industrial-symbiosis-and-the-un-sustainable-development-goals/

Economic benefits (Contributing to the achievement of SDGs 8, 12)

1. Reduction of expenses resulting from waste disposal
2. Creation of new value chains contributing to the development of stronger regional economies[20]
3. Potential cost savings
4. Protection of important natural resources to prevent future scarcity thus contributing to economic resilience (Resource security)[21]

Social benefits (Contributing to the achievement of SDGs 8, 12)

1. Increased employment opportunities[22]
2. Creation of more harmonious business environment based on trust and intimacy[23]
3. Extension of knowledge and practical know-how on how waste management can be transformed into a sustainable and growth-oriented business[24]

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[20] Scaler project. (2020). Available online: https://www.scalerproject.eu/why-industrial-symbiosis/the-benefits

[21] European Committee for Standardisation-ECS. (2018). CEN Workshop Agreement 17354. Available online: https://standards.iteh.ai/catalog/standards/cen/e193aac6-2c81-442d-9309-ecdcdd62b24f/cwa-17354-2018

[22] Scaler project (2019), op.cit.

[23] Hewes, Anne K. & Lyons, Donald I. (2008). The Humanistic Side of Eco- Industrial Parks: Champions and the Role of Trust. Regional Studies, 42:10, 1329-1342, DOI: 10.1080/00343400701654079.

[24] Scaler project (2019), op.cit.

2.1.2 Prerequisites & barriers

In order for the IS ecosystem to develop and operate in a harmonized way, the related industries should be interconnected in order to keep the chain running. These industries should at least:

a. Have full access to the production and consumption data of the related business ecosystem;
b. Have adequate expertise, capacity and logistics;
c. Will to share their services;
d. Collaborate extensively through networks
e. Innovate.

However, the promotion of industrial symbiosis is considered to face significant barriers including among others[25]:

a. The lack of interest or motivation of the various potential symbiotic partners
b. The lack of knowledge or expertise for the adoption and implementation of the IS model
c. The lack of financing for the transition and promotion of IS
d. Market immaturity
e. A smaller cost efficiency of the model compared to the linear model
f. Technological bottlenecks that inhibit the interconnection and exchange of information of the industries.

Technological enablers

Key components of Industry 4.0 such as IoT, Big Data Analytics and Mobile devices/connectivity are expected to play a key role for the development of smart industries and factories. New technologies will enable:

1. The operation of mathematical and computer models which will contribute in decision-making to support and optimize the current and future industrial symbiosis practices
2. The operation of platforms for sharing information on available resources
3. Data-driven analyses to optimize the use of resources[26]

[25] Henriques, J.; Ferrão, P.; Castro, R.; Azevedo, J. (2021) Industrial Symbiosis: A Sectoral Analysis on Enablers and Barriers. Sustainability, 13, 1723. https://doi.org/10.3390/su13041723
[26] Sharebox project. (2020). Available online: http://sharebox-project.eu/

4. Faster networks such as the 5G which are expected to allow industries to track their material flows more seamlessly, building stronger foundations for symbiotic exchanges

5. The functioning of an increasing number of sensors and network capacity that will allow industries to collect massive amounts of data which will be used in order to achieve useful predictions related to production and waste quantities[27]

6. Increased knowledge and expertise sharing through IoT and Big Data Analytic

6. Significant cost savings from the use of smart energy control and optimization systems

7. Better logistics.

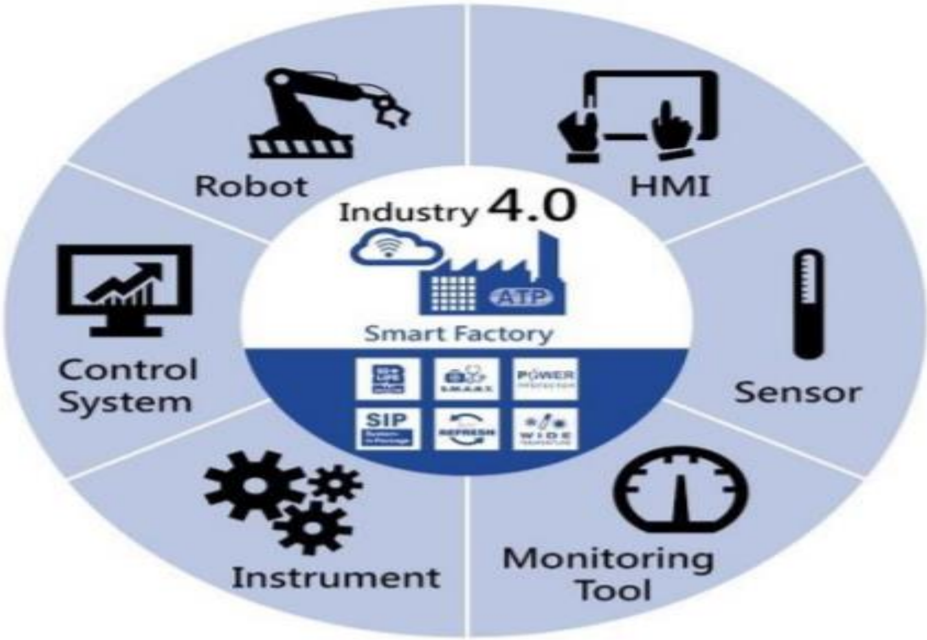

Figure 2. Smart factories and industry 4.0 (Sharebox project, 2021)[28]

2.1.3 Industrial symbiosis & 4IR: a policy perspective

From an EU policy perspective, no dedicated 'Industrial Symbiotic legislation' nor specific policies or initiatives dealing with interlinks between IS & Industry 4.0 have been established until now. Industrial symbiosis -at this stage- is promoted by the public and private sector at a pilot scale through the implementation of experimental projects. Several IS projects are funded mainly through the HORIZON 2020 programme and other European financial instruments.

[27] Rolnick, D., Donti, P. L., Kaack, L. H., Kochanski, K., Lacoste, A., Sankaran, K., et al. (2019). Tackling climate change with machine learning. arXiv [Preprint]. arXiv:1906.05433.
[28] Sharebox project (2020), op.cit.

EU-funded Industrial Symbiosis projects
❖ Industrial Symbiosis for a Resource Efficient Circular Economy (Symbi project-Interreg Europe)[29]; ❖ Helping industries increase efficiency through resource sharing (Scaler project, HORIZON 2020)[30]; ❖ Industrial Symbiosis in energy intensive industries (Coralis project, HORIZON 2020)[31]. ❖ Symbiotic networks of bio-waste sustainable management (SYMBIOSIS, Interreg - IPA CBC)[32]

The IS has been recognized at EU level as a sustainable and useful tool for contributing to carbon neutrality in the 'Circular economy Action Plan for a cleaner and more competitive Europe' which has been developed in the framework of the 'Green Deal'[33]. It is also considered and promoted in several other EU policies and EU initiatives such as:

1. The amended Waste Framework Directive of 2018
2. The 'European Industrial Strategy'
3. The EU initiatives aimed at 'Digitalising European Industry'
4. The 'EU-wide network for industrial symbiosis - CircLean'.
5. The EU Emissions Trading System (EU ETS)
6. The European Energy Union.

Moreover, the European Committee for Standardization is building a consensus on standard terminologies and methodologies for industrial symbiosis[34].

[29] Symbi project-Interreg Europe: https://www.interregeurope.eu/symbi/
[30] Scale project : https://www.scalerproject.eu/
[31] Coralis project : https://www.coralis-h2020.eu/
[32] SYMBIOSIS : https://symbiosisproject.eu/
[33] Circular economy Action Plan (CEAP). 2020. Available online: https://ec.europa.eu/environment/strategy/circular-economy-action-plan_en#:~:text=The%20European%20Commission%20adopted%20the,new%20agenda%20for%20sustainable%20growth.&text=It%20is%20also%20a%20prerequisite,and%20to%20halt%20biodiversity%20loss
[34] European Committee for Standardisation-ECS. (2018). CEN Workshop Agreement 17354. Available online: https://standards.iteh.ai/catalog/standards/cen/e193aac6-2c81-442d-9309-ecdcdd62b24f/cwa-17354-2018

The World Bank Group also collaborated with UNIDO and the Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH towards the development of an international framework for eco-industrial parks that include industrial symbiosis as a basic component[35].

At the national level, many EU countries promote industrial symbiosis through relevant policies. Such cases are Greece and Italy. The promotion of industrial symbiosis is included as one of the main axis of the new 'National Action Plan on Circular Economy[36]' in Greece while Italy moves towards the same path through its 'Circular Economy Action plan'[37]. It should be stressed that no concrete connection between industrial symbiosis and its technological dimensions is explicitly mentioned in the above initiatives.

2.1.4 Conclusions

To conclude, the role of industry 4.0 in the promotion of Industrial Symbiosis is not clearly identified or visible at the EU level in terms of concrete EU policy initiatives connecting both ideas and concepts. Several initiatives at the EU and national levels promote IS while more pilot and experimental projects are progressing providing an insight and know-how on the achievement of environmentally and socioeconomically sustainable symbiotic projects. Moreover, the exact technological prerequisites of IS are not clearly identified. The role of industry 4.0 in the development of IS should become clearer at the EU level in order to anticipate the emergence of possible technological bottlenecks through the development of relevant studies and policies which will explore and address the relation and connection between the two ideas and concepts in a more concrete and targeted way.

[35] Shi, Lin. (2020). Industrial Symbiosis: Context and Relevance to the Sustainable Development Goals (SDGs). 10.1007/978-3-319-71062-4_19-2.

[36] National Action Plan on Circular Economy : https://ypen.gov.gr/wp-content/uploads/2021/03/NEO_SXEDIO_DRASIS_KUKLIKH_OIKONOMIA.pdf

[37] Circular Economy Action plan: https://circulareconomy.europa.eu/platform/en/strategies/towards-model-circular-economy-italy-overview-and-strategic-framework

2.2 Case study 2: Climate Change Adaptation & Industry 4.0

2.2.1 Adaptation to climate change

Climate change adaptation (CCA) refers to adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts[38]. It basically means taking action to *prepare for* and *adjust to* both the current effects of climate change and the predicted impacts in the future[39]. These impacts include, among others and depending on each region: a) Rise of sea level, b) Increase of floods, c) Increase of water scarcity, d) Desertification, e) Rise of mean temperature, f) Increase in the frequency of extreme meteorological phenomenon.

The aforementioned impacts of climate change mean that all sectors of the economy should start taking preventive actions, change practices and operate under different standards to adapt to climate risks but also in order to benefit from potential opportunities that may arise (climate opportunities).

Climate change adaptation actually covers all the SDGs horizontally since it encompasses the sustainable development of all sectors (even though SGD 13 is dedicated to 'Climate Action').

[38] UNFCCC. (2021). What do adaptation to climate change and climate resilience mean? Available online: https://unfccc.int/topics/adaptation-and-resilience/the-big-picture/what-do-adaptation-to-climate-change-and-climate-resilience-mean

[39] European Commission, 2021. Adaptation to climate change. Available online: https://ec.europa.eu/clima/policies/adaptation_en

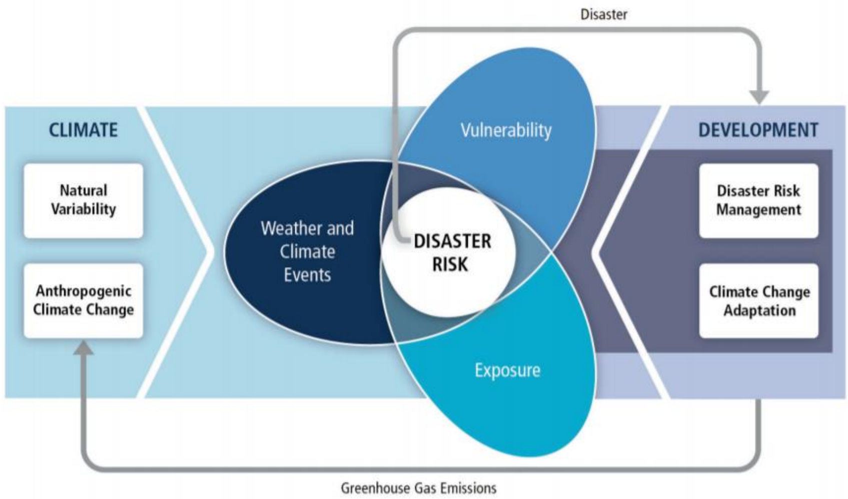

Figure 1. Links between adaptation, sustainable development and disaster risk reduction (IPCC, 2021)[40]

2.2.2 Climate change adaptation & Industry 4.0

Industry 4.0 and CCA are closely interrelated:

- First, CCA is affected by the global emissions of the industrial sector which are estimated to account for almost 30 per cent of total global greenhouse gas emissions[41]
- Second, CCA technologies foreseen to be developed and applied within Industry 4.0 era are expected to contribute decisively to the adaptation of all economic sectors to the impacts of climate change.

More precisely, these technologies include[42]:

1. Information and communication technologies (ICT)
2. Cyber-physical systems that use ICTs for the monitoring of physical processes
3. Network communications including wireless and internet technologies
4. Simulation, modelling and virtualisation
5. Big data and cloud computing
6. Artificial intelligence.

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[40] Intergovernmental Panel on Climate Change (IPCC). (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. Special Report of the Intergovernmental Panel on Climate Change. Summary for policymakers (figure SPM.1, p.2). Available online: https://goo.gl/1gNpEs

[41] Climate-KIC. (2017). Industry 4.0 could be a key player in mitigating climate change. Available online: https://www.climate-kic.org/opinion/industry-4/

[42] Europarl. (2015). Industry 4.0 Digitalisation for productivity and growth. Briefings. Available online: https://www.europarl.europa.eu/RegData/etudes/BRIE/2015/568337/EPRS_BRI(2015)568337_EN.pdf

Through advanced applications, new technologies can contribute substantially to climate change adaptation:

- All sectors of the economy have the potential to minimize their energy and water consumption through the use of smart sensors and precision technologies developed under Industry 4.0, thus also adapting to the impacts of climate change. For instance, smart sensors and software may control the energy and water flows for efficient consumption contributing consequently to efficient energy and water consumption.
- Simulation and modelling may be a useful tool for simulating the impacts of climate change and designing processes and technologies in a more resilient and sustainable way. For example, CCA-related risks such as wildfires and floods could be better simulated and enable the prevention of associated costs and losses. Wildfires could be prevented with the use of early warning sensors while they could even be extinguished with the use of wildfire modelling. Early warning systems could also contribute to the reduction of casualties from extreme weather events.
- Fast network communications, platforms and Big Data may prove to be critical in the exchange and processing of information on climate events. Moreover, the exchange of information and know-how between countries may play a critical role when adapting to climate change.

2.2.3 Climate change adaptation and technological prerequisites: a policy perspective

Climate change adaptation is promoted from both the public and private sectors through several policies and initiatives and it is a central part of the European 'Green Deal Action Plan' through the development of a '*New EU Strategy on Adaptation to Climate Change*'.

Existing or under development EU policies and initiatives include among others:

- The EU Strategy on adaptation to climate change
- The 2050 long-term strategy[43]
- The European Climate Law

[43] https://ec.europa.eu/clima/policies/strategies/2050_en#:~:text=The%20EU%20aims%20to%20be,action%20under%20the%20Paris%20Agreement

- The 2030 climate & energy framework
- The EU Emissions Trading System (EU ETS).

Moreover, a large number of CCA projects are currently funded from different financial instruments such as the LIFE programme, HORIZON2020, Urban Innovative Actions, etc. At the national level, 25 EU Member States (MS) have adopted a national adaptation strategy (NAS) and 15 MS have developed a national adaptation plan (NAP)[44]. However, as in the case of Industrial Symbiosis, the role of industry 4.0 in CCA is not clearly identified through a concrete EU policy or initiative. A broad policy framework exists at the EU and national level for CCA but with no clear reference on how Industry 4.0 will promote effectively CCA.

2.3 Case study 3: The 'Energy-Industry 4.0' nexus

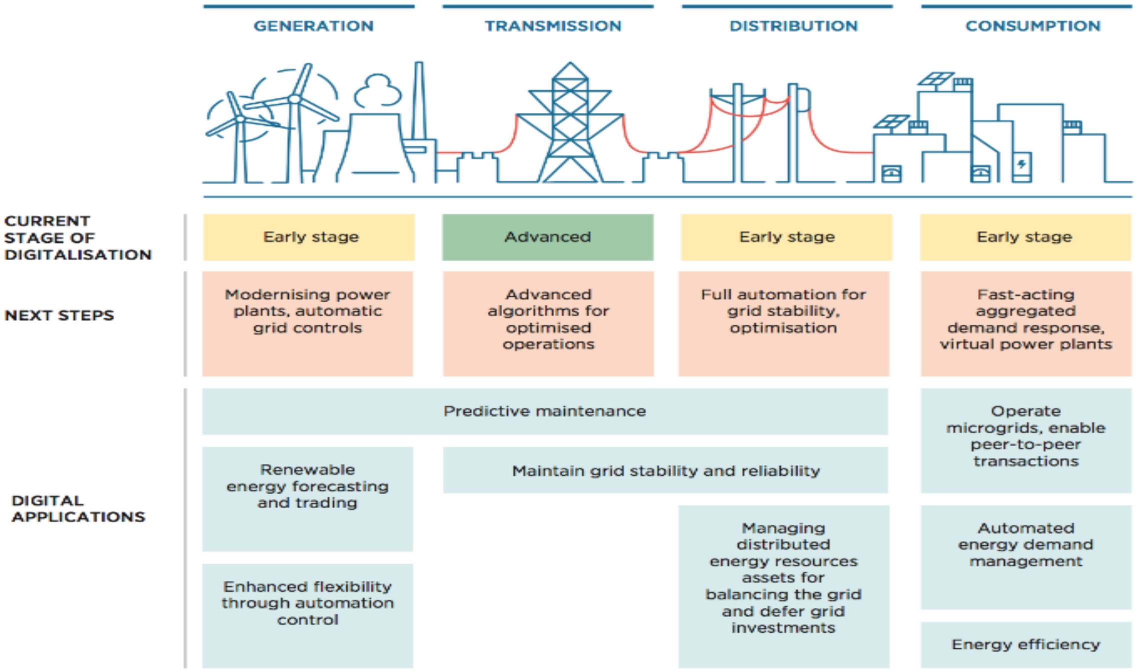
2.3.1 A comprehensive reconfiguration of the energy sector

The energy system is experiencing a holistic reshuffle due to trends, changes, innovative ideas and sector coupling affecting Generation, Transmission and Distribution operators, channels and supply chains and, finally the end users, which tend to become "prosumers". The new energy slang illustrates their opportunities to perform in bi-directional transactions. Among these, the new player, Storage, is going to assume a significant role in energy transition and transformation.

Emerging needs of the energy system

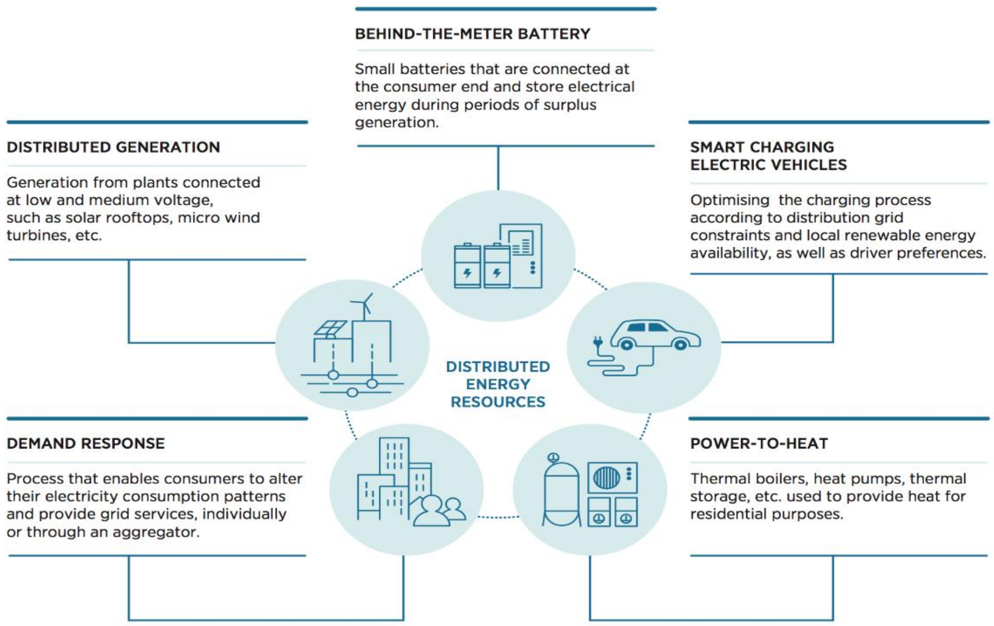
Generation needs to incorporate flexibility ensured by small scale and decentralized units, enhancing transition towards renewables and local generation. At the same time electrification of a significant fraction of the end user sector, such as Electric Mobility, will probably increase the loads across Transmission Grids. On the other hand, Power to X applications will offer a helpful "buffer" for load management, depending on energy demands, fuel/electricity prices and load convergence of end users across several time periods.

[44] Climate Adapt. (2020). Number of countries that have adopted a climate change adaptation strategy/plan. Available online: https://climate-adapt.eea.europa.eu/metadata/indicators/number-of-countries-that-have-adopted-a-climate-change-adaptation-strategy-plan



Innovative Transformations within the Electricity Supply Chain and the corresponded Digital Applications that are emerging

All these will affect the priorities of each player, acting either as individual prosumers or as small-scale energy cooperatives or even as synergy makers across medium-large scale aggregated fields. Actually, their capabilities to exchange energy, incomes, and mutually beneficial collaborations can be further expanded.

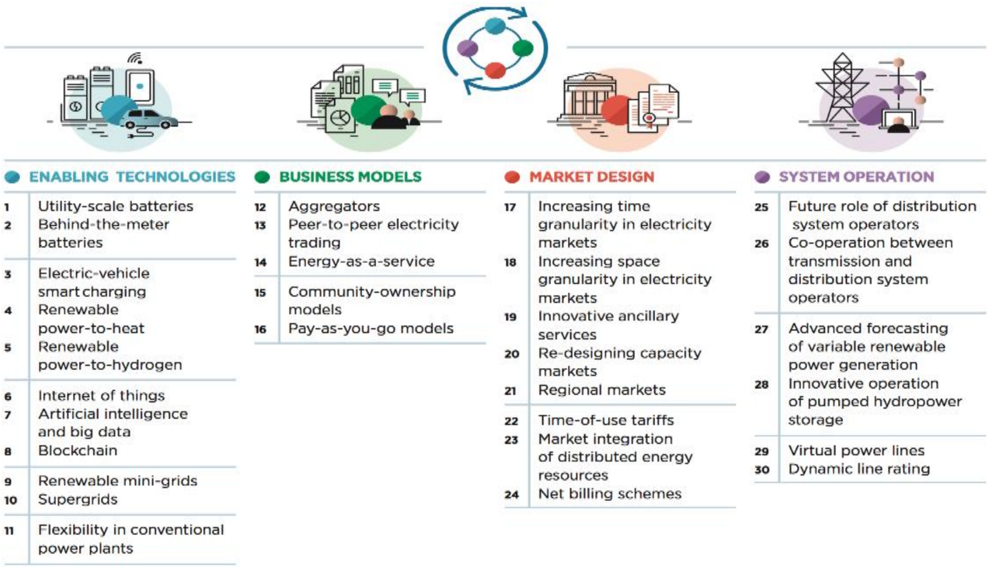


Distributed energy sources that decentralise the power system, IRENA (2019).

According to IRENA[45], the Innovative Framework includes 30 types of innovation across 4 main dimensions:

1. Enabling Technologies
2. Business Models
3. Market Structure & Design
4. System Operation

[45] IRENA 2019, Innovation Landscape for a Renewable Powered Future, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Feb/IRENA_Innovation_Landscape_2019_report.pdf



The Landscape of Innovations, enhancing the integration of Variable Renewable Sources[46].

The Integration of variable renewables are highly depended on **enabling technologies**. All Storage applications and digital technologies are collaborating in order to facilitate new developments, niche market areas and flexible paradigm shifts. Energy generated as electricity can now be managed upon several types of storage, not only by large or domestic (behind the meter) batteries, but also by means of Reverse flow hydro-plants, Smart Charging for EVs and Vehicle to Grid (V2G) options, thermal storage, Conversion to Hydrogen and to e-(non-fossil) green fuels/gases (Power to Heat, Power to Hydrogen, Power to Liquid, Power to X).

2.3.2 Digital Enabling Technologies for the new energy system

Digital technologies are taking the significant role to re-configure the energy system by three (3) main interactions:

1. Data gathering and analysis
2. Remote control of energy assets
3. Capacity of flexible conversion from one energy carrier to another. This specific interaction can ensure minimum losses, *maximum integration of renewables*,

[46] IRENA 2019 & 2021. World Energy Teansitions Outlook, 1.5 C Pathway, https://www.irena.org/publications/2021/March/World-Energy-Transitions-Outlook

*minimum market risks f*or all players, energy justice, strengthening of labour multipliers and promoting maximum industrial green synergies.

A brief presentation of digital enabling technologies for the energy sector is provided below.

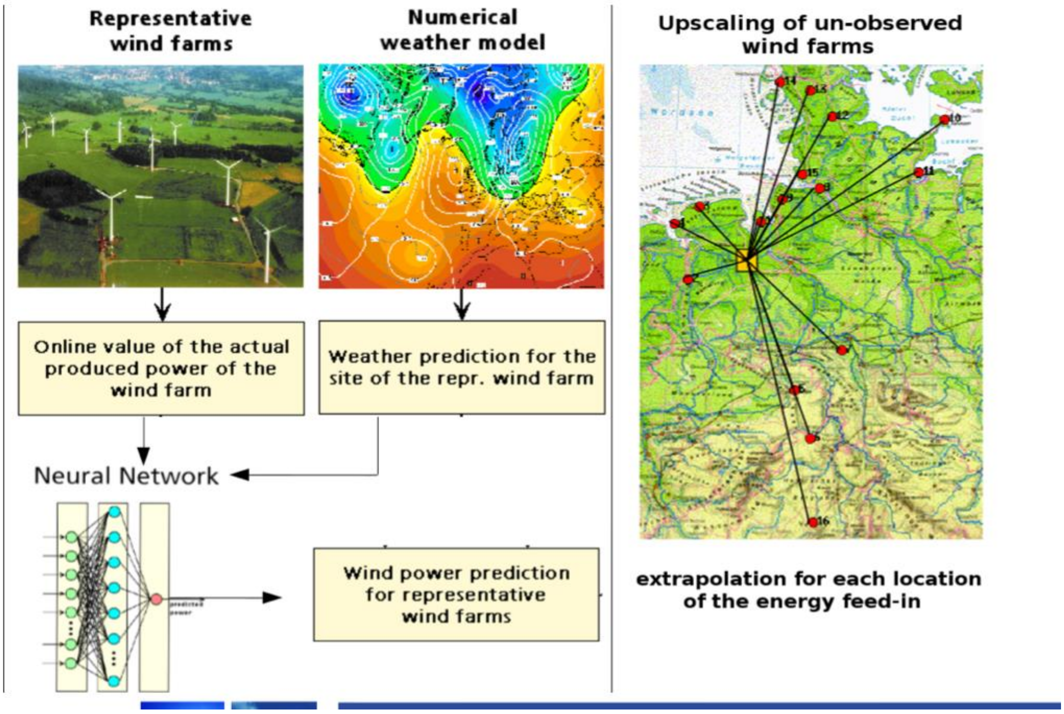
Internet of Things (IoT)

The Internet of Things (IoT) helps devices belonging to home, industrial or national grid equipment to communicate one each other in real time and exchange data. Being influenced by algorithms, IoT can support the interaction of loads, demands and response among energy resources of a flexible, resilient and decentralised system. IoT can also smooth the variances and uncertainty of renewable sources due to weather conditions if forecasting is implemented.

Artificial Intelligence & Big Data

The most significant gain to decision tree learnings, applied to energy management and markets, is supported by combining sufficient data sets and effective machine learning tools. Forecasting of functional renewable energy production and optimization of distributed sources incorporated in modern energy systems are the best examples of such applications. Cloud-based processes, combined with modern mathematics improving forecasting frequency (i.e. 15 minutes instead of 1 hour) and high-resolution weather estimations decrease uncertainty for functional and grid operators, improving the deployment of renewables.

Additional technologies such as cloud-imaging provides representation and image evidence of natural events (i.e. solar radiation or a fluid leakage detection) in combination with the capacity to monitor natural phenomena (i.e. cloud movement) and censoring of rotational and thermodynamic properties of energy generation machinery (i.e. wind turbines).



A. Bouras1 T. Reinartz (2016 Italy)

Block-Chains

This distributed ledger opportunity for security transactions can be recorded within an energy network. Without a necessary intermediate "contract supplier", decentralised energy networks can interact with electricity grid, in terms of services and transactions, with lower costs. Information is verified and a niche networking and market area is possible to be expanded with transparency and cyber security. There are many energy start-ups relevant to block-chain technology developed in Europe. Most of them in Germany and Netherlands. A significant amount has been also invested across the US. Up to now, peer to peer (P2P) trading is the most spread and feasible worldwide. Contracts and block-chains between independent producers – prosumers and Central Grids have not been developed yet[47].

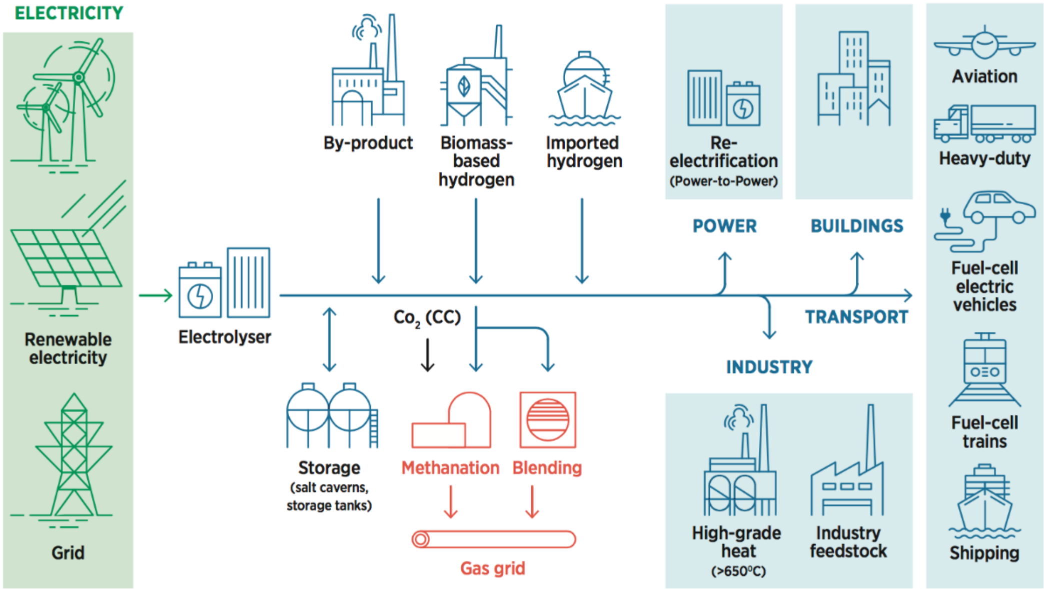
[47] TENNET (2017b), "Europe's first blockchain project to stabilize the power grid launches: TenneT and sonnen expect results in 2018" https://www.tennet.eu/news/detail/europes- first-blockchain-project-to-stabilize-the-power- grid-launches-tennet-and-sonnen-expect-res/ https://www.tennet.eu/fileadmin/user_upload/Our_Key_Tasks/Innovations/blockchain_technology/QandA_webinar_Equigy_and_CBP_11_september_2020.pdf

Combinations of Enabling Technologies

Combinations of enabling technologies, promotes several kinds of synergies between innovations that permit grid services based on distributed energy resources. A Virtual Power Plant, relied on a software and a smart grid, can include innovative sub-systems such as smart EV charging and V2G service, renewable Power to X, batteries “behind the meter” etc., in order to optimise decentralised energy systems by remote control. Information mining by network smart meters will help the grid to operate in a more efficient way, reducing the bill charges because of the alternatives potential given by aggregators to prosumers and vice versa. It should be a kind of Digitalized “Responsible” Consumption and Production, something similar to a “Digital LCA”. Thus, IoT, Machine Learning and Block-chains can be complements to green transport, sustainable domestic/commercial heating, renewable energy storage and conversion to e-fuels and every kind of energy carrier that is necessary to enter a commercially sustainable path through economies of scale.

Artificial Intelligence and Big Data are catalysts for the implementation of the large-scale synergies among industries and energy carriers, more specifically for Power to X Solutions. Hydrogen seems to have a crucial role, as an energy carrier, when converting the renewable electricity to hydrogen and then to use this for Green and Sustainable application in the industrial sector, including Cement industry, Steel Industry, Gas Grid and Refineries that may produce green fuels or decarbonize their process.

Figure 34 Integration of VRE into end-uses by means of hydrogen



Source: IRENA, 2018d.

The e-fuels which are going to replace fossil fuels allow end users to keep their existing technologies, so they become an alternative i.e. to EVs or other future electrification carriers. Another option is the Power to chemicals, if hydrogen is going to become the feedstock for methanol or ammonia production[48]. Germany is going to invest over 1 billion Euros in order to develop Power to X mode, especially for producing Hydrogen and Synthetic Methane. Therefore, it is highly important that Digital Platforms integrate all these facilities.

Hybrid Marketplace Solutions

One more option is the development of a Solar Cloud. The PV owners are restoring the surplus energy by means of an Exclusively Digital cloud assembly. So, they can get back any amount of their restored energy, using their virtual account. They can use this electricity for other places also, not only at their home or their domestic facility. In other words, they don't need even to spend money for a real battery facilitation. By the same mode, other consumers who don't own any Solar Equipment, have the chance to purchase and use green power. At the end of the day, enabling technologies

[48] IRENA (2018), Hydrogen from renewable power: Technology outlook for the energy transition https://www.irena.org/publications/2018/Sep/Hydrogen-from-renewable-power.

that are necessary for storage and on demand use of renewable energy could be only IoT, AI and Block-chain, without any battery equipment for the individual Prosumer.

Conclusions for 1rst Step Actions and Immediate Policies

First, policy-makers should focus on:

- ❖ Access and affordability of weather historical data and the corresponding solution models and toolboxes for small players.
- ❖ A clear regulatory framework regarding digital technologies enabling network assets against the -business as usual- conventional properties (i.e. cloud storage for excess energy against physical batteries).
- ❖ The establishment of an IoT - AI platform, suitable for the Decentralised energy sources, available for prosumers, cooperatives, innovative synergies, aggregators, Grid Operators, infrastructure facilitators. Digital platforms should enhance prosumers position, the proper price signals for them, their role as collective facilitators, their advanced participation and ensure the protection of their personal data and private preferences.

2.3.3 Future topics for the maturity of enabling digital applications in favour of social and energy justice

AI-ML in the energy co-operatives and synergy schemes demand and charging policies

The society of consumers needs a reflective, adaptive and flexible structure of their consumption preference without any violation of consumers' privacy and personal preference discretion. A multi-agent coordination algorithm is capable to format the energy demand of an energy cooperative or of a synergy group.

AI- Block-chains and VPP

A transparent, decent, efficient Peer to Peer (P2P) energy trading implementing Virtual Power Plants and Smart Contract scheme should be adopted only if a public block-chain based platform and the necessary crypto-graphic test can be developed with the corresponding algorithmic steps. Deep learning should be utilized. Decent efficiency optimization of security mechanisms, are necessary for enabling the platform as a profitable tool for all stakeholders[49].

On Block-chains

The development of a model that is matching the sustainable energy savings with an energy-based monetizing system, digitally awarding these savings could promote incentives for the end-users and support economic multipliers.

Smart meters enabling historical data should support forecasting models. Deployment of ICT equipment, of smart cities concept and real-time monitoring are very essential. In addition, investments in rural areas should extend this model, beyond the common urban model of smart city as usual considered. The proposed P2P transactions should be further discussed not only including big companies and centralised utilities, but also decentralised networks, energy cooperatives and open – democratic schemes. For these reasons, security and affordability become a first priority[50].

Considering that, all kinds of Block-chains (including energy trading), have to anticipate the Trilemma: *Decentralization- Scalability- Security*. You can have the 1rst and the last property but not the middle one[51]. On the other hand, if a centralised "master" can support a high level of transaction rate, keeping immunity of the system, this is not going to be a decentralised system. Vulnerabilities of many smart contracts have been reported some years ago. Testing a non-changing program that encodes a smart contract on a block-chain platform is very essential, as an aftermath from all previous cases[52].

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[49] Yao, Soran et al (2020), Peer-to-Peer Energy Trading in Virtual Power Plant Based on Block-chain Smart Contracts https://www.researchgate.net/publication/344360971_Peer-to-Peer_Energy_Trading_in_Virtual_Power_Plant_Based_on_Blockchain_Smart_Contracts

[50] Marinakis, Doukas, Koasidis (2020). From Intelligent Energy Management to Value Economy through a Digital Energy Currency: Bahrain City Case Study. https://www.mdpi.com/1424-8220/20/5/1456

[51] Abadi, J., & Brunnermeier, M. (2018). Blockchain economics (No. w25407). National Bureau of Economic Research, https://www.nber.org/system/files/working_papers/w25407/w25407.pdf

[52] Bartoletti, M., & Pompianu, L. (2017, April). An empirical analysis of smart contracts: platforms, applications, and design patterns. In International conference on financial cryptography and data security, https://www.researchgate.net/publication/315454656_An_Empirical_Analysis_of_Smart_Contracts_Platforms_Applications_and_Design_Patterns

Based on the above-mentioned reference, a further research, test and bench marking on which should be the preferred choice for energy platforms, either based on Neighbourhood Central Storage (when the energy is restored into a central node until one/some consumer(s) request this), or alternatively based on Direct Energy Exchange (when the consumer purchases energy from the producers directly, without any central storage interference)[53].

2.4 Proposed Steps for Long Term Strategies within National European and Global Frameworks

- Long term strategies must be prioritised against short term profits. This should go across Policy makers, Infrastructure operators' master plans, investors' interests and the perspectives of the energy / environmental companies. The design of Grids, of the upstream/conversion/supply chains, installations and markets should be adopted accordingly.

- The holistic frame of innovative (inter)actions should be considered, instead of individual—learning by doing—case studies. Synergies among several industry sectors and across alternative enabling solutions should be integrated within national or regional plans of digital/ sustainable transition context.

- On the other hand, the solutions, innovations, trial and demonstration approach is essential under experiments and tests financially and legislatively covered by regulatory authorities, that can promote the right framework, allowing Fin-Tech start-ups to implement their experiments, under the supervision of the Master Planner (i.e. Regulatory Authorities of Energy and Digital Sector).

- Strong incentives and degrees of freedom must be provided to independent and cooperative entities of decentralised networks that are willing to anticipate energy poverty and inequalities.

- A clear communication of benefits and obligations for companies of the energy and industrial sectors are needed in order to implement a coherent plan for

[53] The Blockchain as Enabling Technology for Energy Communities. A Review on the Potentials of the Blockchains and the Importance of the Legislative Framework in the Energy Sector. (2019), Universita Degli Stadi, Rome, http://www.foroeuropa.it/documenti/rivista/TesiFrancescoMariaFranza.pdf

the optimal output of synergies and initiatives [collaboration between an Hydrogen/Green Gas Infrastructure Public Owner, steel – cement industry, (green) fuel refining and the downstream suppliers of electricity, green fuels for domestic, commercial, industrial, marine and transport applications].

- Innovative digital applications and user-friendly software (even used by a mobile phone) are used in TV appliances, drones for fun etc., but not applicable in a massive scale across the energy industry, carriers and the supply chain. It is time for further steps.
- Knowledge and innovation should be accessed by all players, especially by those who claim for equal opportunities in the energy. The inclusive narrative of innovation is very crucial.
- Last but not least, further research should also address the similarities, the coverage in priorities and the challenges throughout a multi-level cross mapping of the derived Strategies and Policies for Digitalization and Energy/Sustainability/Environmental Context across National, Regional, European and Global Level.

3. Concluding remarks: In search of an environmentally sustainable paradigm

As presented in section 1, the carbon and environmental footprint of the sector is increasing at unsustainable rates. This trend is the result of the prevalence of an extremely commercialized market model leading to excessive consumption of digital services, equipment and devices. The perpetuation of the market model will soon confront European societies with contradictions characterizing the environmental and digital transitions. A revision of this model is thus urgent. First, for minimizing adverse consequences. Second, and mainly, for unlocking the unexploited socio-environmental potential of the 4IR illustrated through the three case studies presented in Section 2. In order to take advantage of this potential, several key-challenges need to be addressed by European and national authorities, market players and stakeholders (beyond the one already mentioned in previous sections).

3.1 Evaluation of technological choices

Efforts of the EU for the reduction of the carbon footprint mainly focus on efficiency gains through technological solutions. This approach neglects the impact of 'rebound effects' (i.e. increase in consumption due to efficiency gains and lower productions costs) and the necessity to question the market-based development of digital services which allows unrestrained and unnecessary levels of consumption. A drastic shift regarding the criteria of evaluation of technologies should be considered. Such an approach should guide policy makers to move on from the current techno-centric approach leading to the acceptance of "*whatever is achievable from an engineering point of view*" and "*whatever is marketable from a business point of view*" **to what is essential and needed from a social point of view**[54]. Pertinence of a technology should be evaluated according to social, societal, health and environmental criteria considering the entire cycle of products (production, consumption, maintenance, waste/recycling) and of material infrastructures (data centers, networks). Case

[54] EuroMemo Group (2019), 'A Green New Deal for Europe –Opportunities and Challenges', EuroMemorandum 2020. Available at: http://www.euromemo.eu/euromemorandum/euromemorandum_2020/index.html

studies presented in section 2 confirm the existence of significant technological potentialities in the industrial sector, the energy system and for the support of climate mitigation and adaptation policies. The gradual de-marketization of the digital industry should prioritize the reallocation of resources from commercial technological products and services of low(er) social value to the development of promising applications contributing to the common good (including environmental sustainability). Such applications include/enable:

(a) Digital technologies for the reduction of the environmental footprint of the agriculture, energy and transport sectors,

(b) The collection of health data for faster and more efficient research, diagnosis and treatment of chronic diseases,

(c) The development of telemedicine,

(d) The use of new technologies for the prevention and management of natural disasters and climate change,

(e) Tackling social and spatial digital exclusion,

(f) Access to data for the design of sustainable urban development policies, for supporting small value chains in the agricultural sector and decentralized energy production networks, etc.

3.2 An EU policy-perspective

It should be mentioned that some of the above priorities are part of the EU strategy "Shaping Europe's digital future". The plan for the recovery of the European economy (EU Next Generation) creates, in turn, favorable conditions for the financing of relevant infrastructure and policies. Besides, in its recent policy brief “Industry 5.0”[55], the European Commission describes a new vision for the European Industry which “*recognizes the power of industry to achieve societal goals beyond jobs and growth, to become a resilient provider of prosperity, by making production respect the boundaries of our planet and placing the well-being of the industry worker at the*

[55] “Industry 5.0 - Towards a sustainable, human-centric and resilient European industry”, European Commission, January 2021. Available at: https://ec.europa.eu/info/publications/industry-50_en

centre of the production process. This approach complements the existing "Industry 4.0" paradigm by having research and innovation drive the transition to a sustainable, human-centric and resilient European industry. It moves focus from solely shareholder value to stakeholder value, for all concerned".

Case studies presented in section 2 have pointed out, among others, several policy priorities in order to foster the contribution of new technologies to sustainable activities of high socio-economic value:

- The role of industry 4.0 in the promotion of Industrial Symbiosis or Climate Change Adaptation is not clearly identified or visible at the EU level in terms of concrete EU policy initiatives connecting both ideas and concepts. This relation should become clearer at the EU level in order to anticipate the emergence of possible technological bottlenecks. Studies and policies which will explore and address the relation and connection between the two ideas and concepts in a more concrete and targeted way are needed as a first step.
- Synergies and cooperation among several industry sectors and across alternative enabling technological solutions should be fostered and integrated within national or regional plans for digital and climate transition
- Strong incentives and degrees of freedom must be provided to independent and cooperative entities of decentralised energy networks that are willing to anticipate energy poverty and inequalities
- Ensuring the collective ownership of data should list among the top priorities of an effective and ambitious regulation of the digital sector.

3.3 Beyond policy improvements: addressing structural barriers

Fully releasing the social and public value of the digital economy runs into two fundamental obstacles:

- **On the one hand, in the extreme market concentration** of the digital industry. The digital market model is dominated by corporate giants (GAFAM, BATX) who seek the maximisation of short-term equity gains through the securing of long-term monopolistic/oligopolistic advantages. Governments are increasingly dependent on technologies and products of the digital oligopoly and under its influence. The power of the digital corporate sector has been reinforced due to significant additional profits and influence generated during the pandemic.

- **On the other hand, in the over-reliance of public policies on market-based policies**. General interest objectives are subordinated to market priorities. Substantial possibilities for the promotion of public policy goals (e.g. through the implementation of a digital public service) are neglected such as the legislative frameworks and shared values of the European Union for Services of General Economic interest (i.e. public services) which refers to the quality, security, affordability, equal treatment, promotion of universal access and rights of service users. Overcoming the strict boundaries of a market and competition law-based governance and establishing a general-interest based democratic regulation of the digital sector and digital platforms, is therefore key in order to maximise their potential for achieving a fair digital and climate transition, gaining the trust of citizens, minimising adverse effects and ensuring the re-orientation of the digital economy from increasing levels of private consumption towards the provision of digital public and common goods.

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